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COGGING TORQUE REDUCTION OF SPINDLE MOTOR FOR IT APPLICATION

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ABSTRACT

Background/Objectives

For precise speed control of spindle motor using permanent magnet for IT application, it is important to minimize cogging torque when designing the motor instead of control topologies.

Methods/Statistical analysis

The design method for reducing cogging torque of spindle motor is proposed by changing magnetization pattern of permanent magnets (PMs) on a rotor. In order to change the magnetization pattern of PMs, design parameters related to shape of magnetizing fixture are selected and optimized. Magnetization performance on magnetizing fixture and cogging torque of spindle motor are analyzed by using finite element method (FEM).

Findings

A spindle motor should be controlled with constant speed feedback control algorithm. However, cogging torque and torque ripple of the spindle motor give a bad effect on constant speed control. There are many researches on decreasing method of cogging torque by using optimal design on spindle motor itself. In the paper, optimal design on a magnetizer in order for magnetization of permanent magnets on the spindle rotor surface is proposed instead of changing design parameters of spindle motor. In the result, cogging torque is decreased by up to 90 per cent without designing the dimension variables of the spindle motor. Moreover, magnetizing process is analyzed by considering initial magnetization characteristics of permanent magnet by using FEM.

Improvements/Applications:

This technique can be used in permanent magnet motor for high precision IT application including robot, dron, and electronic devices such as hard disk.

KEYWORDS: BLDC Motor, Cogging Torque, Finite Element Method, Magnetizing Fixture & Permanent Magnet, Spindle Motor

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INTRODUCTION

A Spindle motor of a brushless DC (BLDC) motor type is widely used in the field requiring precision like computer data storage device, propelling motor for dron and IT application due to their high efficiency and excellent control ability[1, 2]. However, a BLDC motor has considerable cogging torque owing to permanent magnets in a rotor and teeth structure in a stator core which has a bad influence on vibration, acoustic noise and uneven operating speed. For the high accuracy, it is important to decrease the cogging torque as small as possible. The cogging torque is a pulsation torque which is generated when the rotor is rotated without inputting of electrical power in the spindle motor due to reluctance variation in an air gap. The cogging torque has not mainly

effect on average torque. It causes speed ripple and oscillation due to the pulsation torque. Nowadays, several researches related on control algorithm for reducing pulsation torque are introduced. However, there exists limitation for decreasing the torque pulsation with motor controller. The following design methods of spindle motor in order to reduce cogging torque are usually used for engineers[3, 4]. A method adopting skew at a stator or a rotor is very general method to reduce torque pulsation. Shape design with sinusoidal permanent magnet is also well known method. However, it has a defect on power decline. Next, design method of fractional slot per pole and bifurcated tooth is good choice for low cogging torque. However, these methods cannot decrease torque pulsation remarkably[5, 6].

In the paper, in order for operating the motor with constant revolution, firstly the cogging torque of spindle motor should be decreased by making sinusoidal magnetizing pattern in the permanent magnets of a rotor in advance. To make sinusoidal magnetization when magnetizing permanent magnets rotor, the optimal design process of shape design on PM magnetizeris important before starting design of the spindle motor. First, magnetizing fixture for sinusoidal magnetization of PMs is designed with two design parameters related to magnetizing fixture by using response surface method(RSM). Moreover, magnetizing process of PMs is analyzed by using FEM including initial characteristics of PMs. And then, the torque performance of the proposed PM motor is compared with that of basis PM motor.

ANALYSIS MODEL FOR PM MOTOR AND DESIGN OF MAGNETIZER

Figure 1 shows the basis motor with outer rotor type in order to analyze cogging torque reduction attitude. It has fractional slot and pole combination with 9 slots and 12 poles. The stator has three phase windings of 22 turns per slot. The rotor has ring shaped permanent magnets inside of rotor yoke. The material of PMs is Nd-Fe-B bonded magnet with radial magnetization which remanent magnetic flux density is 0.7T. The DC link voltage for an inverter is 12V. In figure 1, magnetic flux lines by FEM analysis is also represented. Specifications of basis model are represented in table 1.

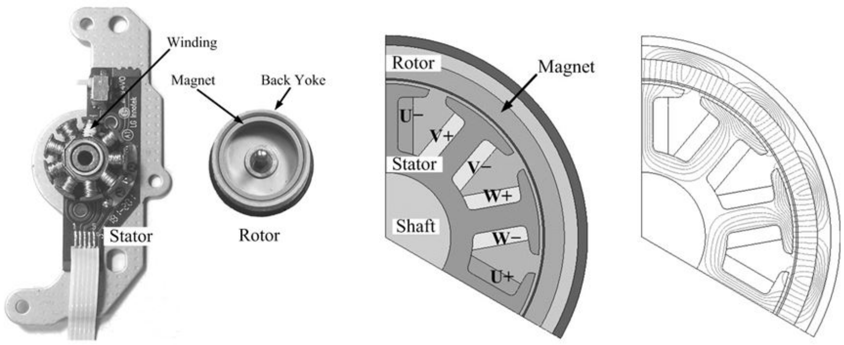


Figure 1: Actual Model of Spindle Motor System and Analysis Model of Spindle Motor for Fem

Table 1: Specifications of Spindle Motor

Parameter	Specification	
Rated Value	Speed	11000 [rpm]
	Input Voltage	12 [Vdc]
Stator	Number of Phase	3
	Number of Slot	9
	Outer Diameter	18 [mm]
	Thickness of Lamination	6 [mm]
Rotor	Number of Pole	12
	Outer Diameter	22.5 [mm]
	Inner Diameter	18.6 [mm]

Permanent Magnet	Material	Nd-Fe-B
	Thickness	1.15 [mm]
	Residual Flux Density	0.7 [T]
	Max. Coercive Force	438200 [A/m]
Air Gap	Mechanical Air Gap	0.3 [mm]

Analysis model for magnetizer in order to magnetize the permanent magnets is presented in figure 2. The magnetizeris composed of 12 slots because the number of pole of motor is 12. The magnetizer has 2 conductors per slot. While the axial length of magnetizing fixture is 15 mm, the axial length of permanent magnets is only 6.5mm just for easy magnetization. Moreover, the air-gap is not existed when the PM rotor is assembled into the magnetizing fixture. Brief specification on magnetizing fixture is shown in table 2.

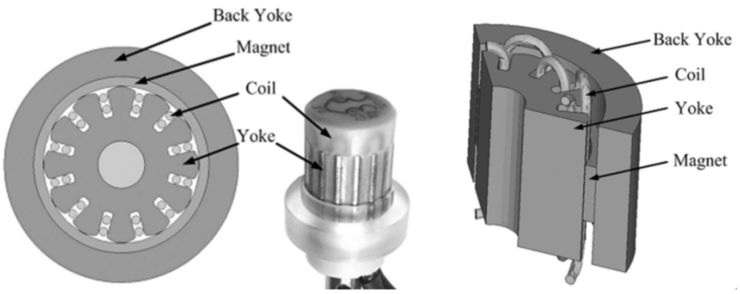


Figure 2: Magnetizer for permanent magnet

Table 2: Specifications of Magnetizing Fixture

Parameter	Specification	
Yoke	Inner Diameter	2.8 [mm]
	Outer Diameter	18.5 [mm]
	Axial Length	15 [mm]
Back Yoke	Inner Diameter	20.9 [mm]
	Outer Diameter	27.9 [mm]
	Axial Length	15 [mm]
	Material	S60
Winding	Diameter	1 [mm]
	Resistance	12.51 [mΩ]

The spindle motor in the research has NdFeB magnet which coercive force is high. Therefore, the magnetic field intensity of the magnetizer should be induced 2~3 times more than 438,200A/m which correspond to coercive force of this magnet. Therefore, it needs the impulse magnetizing system using capacitor discharge. Figure 3 shows an equivalent circuit of impulse magnetizing system with capacitor discharge. The magnetizing system is consisted of the charge part with transformer, rectifier, and switch (S1) and the discharge part with switch (S2) and capacitor (C), and the magnetizing fixture part with freewheeling diode (D) and coil (R, L). If S1 is closed and S2 is opened, the capacitor (C) would be charged. And then if the switches of S1 and S2 are toggled, the capacitor (C) would be started discharge and impulse type current would be induced on magnetizer. The magnetization current is generated with sinusoidal damping form due to the time constant of coil. If S2 is opened at t' (sec), the magnetizing current would be changed from sinusoidal damping form to exponential damping form [12].Figure 4 shows an experiment waveform of the magnetization current as the charge voltage on capacitor is 750V. The maximum magnetization current is about 6,950A at 160μsec. Which corresponds to t' parameter.

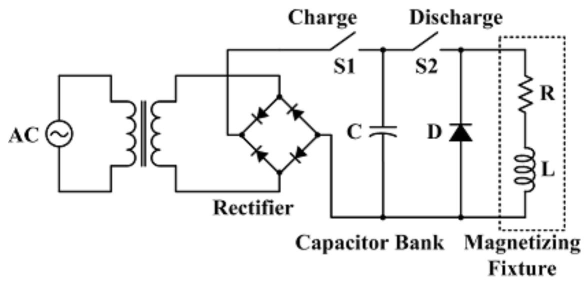


Figure 3: Electrical Circuit for Magnetizing Fixture

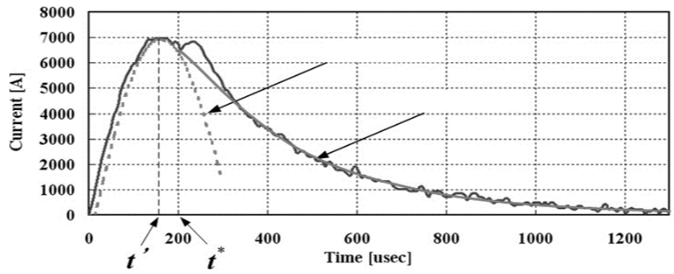


Figure 4: Current Waveforms of Magnetizing Fixture According To Time

Figure 5 shows mesh and magnetic flux line of the basis magnetizer through finite element method when 6,950A current is induced. For the correct analysis, the permanent magnet has precise mesh. It is very important to analyze magnetizer. The number of total elements corresponds to 9694.

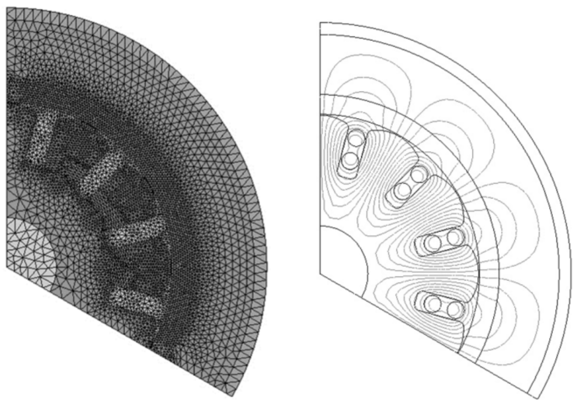


Figure 5: Mesh and Magnetic Flux Line of Magnetizer by FEM

The magnetic flux density in the element meshes of permanent magnet by FEM has magnitude and direction. In order to input the magnetization information after magnetizing permanent magnet, initial magnetization curve of permanent magnet is needed as shown in figure 6. If a mesh in the permanent magnet has B_1magnitude and arbitrary direction of magnetic flux density by FEM analysis, this mesh should have the information of M_1 coercive force and the same direction by considering recoil permeability which decides the slope in figure 6. This process throughout meshes is needed for matching magnetization in PMs after magnetization process.

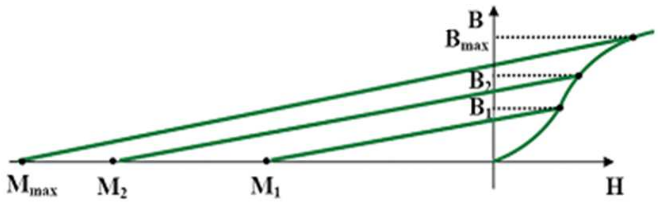


Figure 6: Initial Magnetization Curve of Permanent Magnet and Relationship between B and M

OPTIMAL DESIGN OF MAGNETIZING FIXTURE FOR COGGING TORQUE REDUCTION

In order for optimal design, main effect analysis by using full factorial method and three design values as shown in figure 7 is performed in advance. Each design parameter has three levels. Figure 8 shows main effect analysis result. The design parameter of slot width is not sensitive for cogging torque. Therefore, for response surface method (RSM)[7], two design parameters of radius of curvature and slot depth are considered.

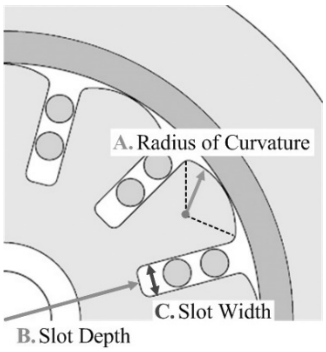


Figure 7: Design Parameters for Optimal Design of Magnetizer

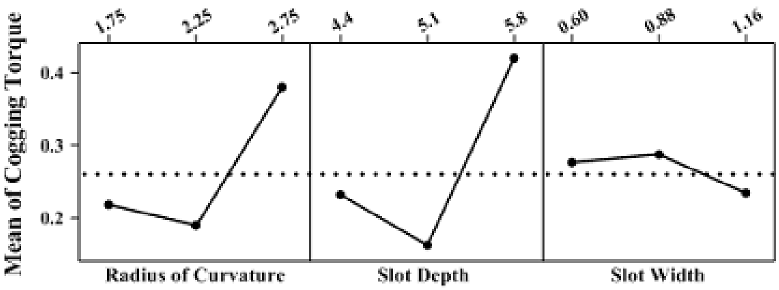


Figure 8: Main Effect Analysis by Full Factorial Method According To Design Parameters

Figure 9 shows the response surface on the cogging torque according to two design variables. The optimal model has the radius curvature of 2.6mm and the slot depth of 4.8mm. The shape of magnetizing fixture for low cogging torque is compared each other as shown in figure 10.

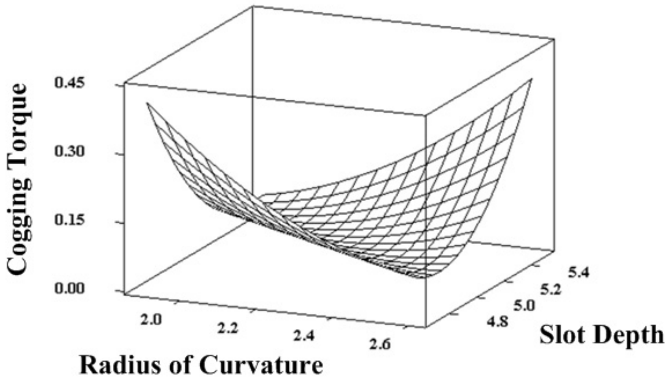
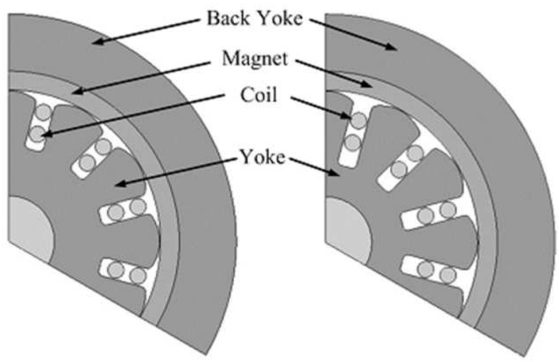


Figure 9: Response Surface for Low Cogging Torque According To Two Design Variables



(a) Actual Model (b) Optimal Model

Figure 10: Comparison between actual model and optimal model for magnetizer

Finally, permanent magnet rotor after magnetization by optimized magnetizing fixture is applied to the spindle motor. The analysis result of cogging torque of spindle motor is only 0.361mNm. Cogging torque of the optimal model decreases 90% more than the actual model by proposed design method as shown in figure 11.

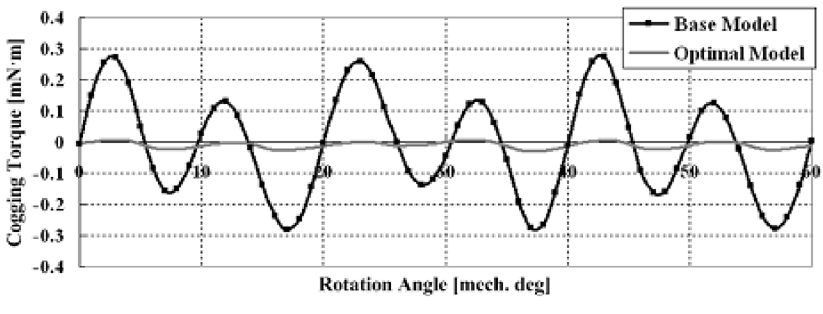


Figure 11: Comparison Results of Cogging Torque of Spindle Motor between Actual Model and Optimal Model

CONCLUSIONS

For the optimal design of low cogging torque, design parameters related to spindle motor structure are directly chosen in general. In the paper, magnetization pattern of permanent magnet is optimally designed instead of spindle motor structure. Therefore, in order for magnetization pattern of permanent magnet, magnetizing fixture and circuit is introduced. Magnetizing fixture for low cogging torque is optimally designed with two design variables related to magnetizing fixture. RSM is introduced for the optimal design. This technique can be used in permanent magnet motor for high precision IT

application including robot, dron, and electronic devices such as hard disk

REFERENCES

1. *T. Siva, A. Sampathkumar.* ***Sensorless control of BLDCM using modified back EMF detection. IJST****. 2015November, 8 (32), 87320.*
2. *R. Meena Devi.* ***Variable sampling effect for bldc motors using fuzzy PI controller. IJST****. 2015December, 8 (35), 68960.*
3. *D. W. Kang, Y. S. Kim, I. G. Kim, J. Lee.* ***Optimization design of an interior permanent magnet motor for electro hydraulic power steering. IJST****. 2016 April, 9 (14), 91100.*
4. *Y. S. Kim, J. Y. Kim, D. W. Kang, J. Lee.* ***Reliability analysis of permanent magnet and air-gap flux density of spoke type IPMSM for driving cooling fans. IJST****. 2012 April, 9 (14), 91101.*
5. *Z. Q. Zhu, D. Howe.* ***Influence of design parameters on cogging torque in permanent magnet machines. IEEE Transactions on Energy Convergence****. 2000 December, 15 (4), pp. 407-412.*
6. *S. Mohammad, T. S. Low, B. Bruhl.* ***Issues in reducing the cogging torque of mass-producted permanent magnet brushless dc motor. IEEE Trans. Industry Applications****. 2004May, 40 (3), pp. 813-820.*
7. *A. Poursafar, A. Amrollahi, H. Barghikar.* ***Machining model of 34CrMo4 steel with several tools using response surface methodolgy. IJST****.2013September, 6 (9), 37140.*